National Aeronautics and Space Administration

Direct Contact Membrane Distillation

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Direct Contact Membrane Distillation (DCMD) is a primary membrane treatment process of the Direct Osmotic Concentration System (DOC), designed to recycle spacecraft wastewater. The DOC combines three separate processes to generate potable water from source separated hygiene water, urine, and humidity condensate. The DOC can achieve a high water recovery rate, has relatively low power requirements and can accommodate wastewater generated by six crewmembers. This system is designed for long-term human space missions, such as Mars exploration, because it minimizes the need to resupply fresh water for crewmember use. The DCMD reclaims water from a feed solution consisting of urine, urine flush, and humidity condensate by creating a 15ºC temperature difference between the concentrated urine loop (at 40ºC) and the product water loop (at 25ºC). This induces a vapor pressure differential across the hydrophobic membrane, allowing water vapor to cross the microporous membrane, while rejecting urea and ammonia nitrogen, among other foulants. The water produced during pretreatment by both the Forward/Reverse Osmosis subsystems (FO/RO) and the DCMD is combined and undergoes secondary treatment by the Aqueous Phase Catalytic Oxidizer (APCO). A Total Organic Carbon (TOC) Analyzer determines the quality of the water produced by the DOC system. The TOC of water produced by the APCO is less than 3mg/L, which fulfills NASA drinking water standards. Two of the four DCMD runs conducted ran to completion, each run lasting approximately seven days, thus amounting to over 500 total hours of operation. Testing resulted in an average of 96% water recovery with 98% TOC rejection. The average water production rate was 1.2 L/hr. Other applications of wastewater recycling technology include a potential water reclamation system for developing countries with scarce water resources.

Introduction

The DCMD, in conjunction with the FO/RO and the APCO make up the DOC System (Figure 1). The first step of the DOC is FO/RO, which treats hygiene water. The DCMD is the second step of the system, treating urine, urine flush and humidity condensate wastewater streams (Figure 2). Lastly, the APCO takes the water produced by the FO/RO and the DCMD and performs post-treatment processing, further purifying the water to meet potable standards. The entire DOC system fits on two racks, with the FO and RO subsystems occupying Rack 1 and the DCMD and APCO sharing Rack 2 (Figure 3). The DCMD uses a heat pump to generate the vapor pressure differential, which acts as the driving force for mass transport across the membrane[1]. The front side of the hydrophobic membrane is in contact with the heated feed solution while the opposite side is in contact with the cooler conditioned DCMD product (Figures 2,4). The water vapor diffuses through the microporous membrane and condenses into the product water loop (Figure 4).

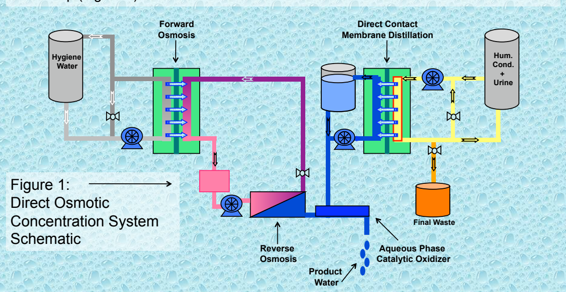


Figure 1: Direct Osmotic Concentration System Schematic

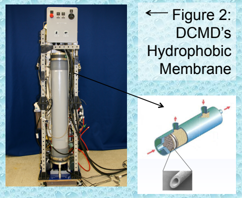
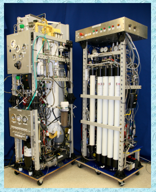


Figure 2: DCMD's Hydrophobic Membrane

Figure 3: DOC System loaded onto two racks



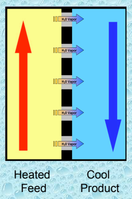


Figure 4: Mass Transfer across hydrophobic membrane

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Experimental Design

The DCMD feed solution is composed of 34.8% urine, 8.7% flush water, and 56.5% ersatz humidity condensate and pretreated with 96% concentrated H_2SO_4 to adjust the pH to 4. Roughly 43 gallons (163 L) of feed is necessary to achieve a 93.5% water recovery rate for a seven day run. Approximately 50 kilograms of feed is added to the DCMD Feed tank as the initial feed solution. The feed tank is continuously replenished during the run as the solution is used up. The concentrated feed solution is recirculated through the DCMD in order to reach the desired water recovery rate[1]. The feed solution is also pretreated with Flocon®, a membrane antiscalant.

The urine used in the experimentation was collected from anonymous donors on-site at NASA Ames Research Center. The ersatz humidity condensate was made based on a transit mission based formula[2]. A hydrophobic polypropylene Micro-dyn® membrane was used in the distillation process and a commercially available household heat pump was used to maintain the temperature difference between the feed and product solutions[3] (Figure 5).

A sample of the feed solution and product water was obtained every hour (Figure 6). The electrical conductivity, pH, and temperature of the feed and product samples were measured and recorded. The weight of the product tank was also noted in order to calculate production rate. The feed and product samples were stored in 40ml vials and refrigerated before undergoing TOC and ion analysis at the Analytical Chemistry Laboratory.

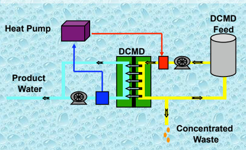
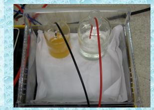


Figure 5: DCMD with attached heat pump

Figure 6: Collection of feed and product samples



Results

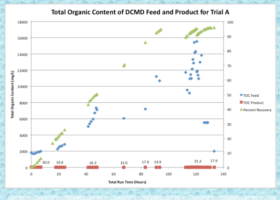


Figure 7: TOC of feed and product during Trial A and percent water recovery overall

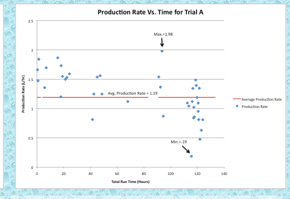


Figure 8: Production rate of water over time during Trial A

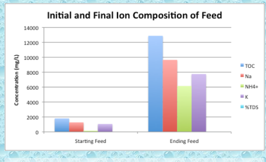


Figure 9: Starting and Ending Cation Composition of Feed

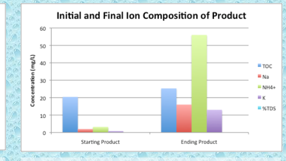


Figure 10: Starting and Ending Cation Composition of Product

The results of Trial A are presented in figures 7, 8, 9, and 10 and are representative of the overall obtained results. The gaps in between the data in the graphs represent times when the DCMD was running overnight and hourly samples were not collected. The TOC of the feed solution varied from 1799 mg/L at the start of the first run to 18408 mg/L at the end of the first run. The average TOC of the resulting product water was 21.3mg/L. TOC output values are preferred to not surpass 30mg/L for the DCMD. The average water recovery rate of the conducted trials was 95.9% and the average production rate was 1.2L/hr. Analysis of samples confirmed that as the run progressed, the feed solution gradually became more concentrated, leading to increased TOC and cation values. Average TOC rejection of the completed trials was 98.3%.

Conclusions

Continuous testing of the DCMD proved that it is a reliable treatment for urine and humidity condensate wastewater streams. The observed TOC rejection has exceeded expectations. Recommendations for future studies that may enhance performance of the DCMD include researching a more efficient heat pump, compatible in microgravity environments. Another suggestion is to monitor the pH of the feed solution more thoroughly. The pH of the feed solution would increase throughout the run, due to the breakdown of urea, which releases ammonia and increases the basicity of the solution. It is not yet known if this caused a significant impact on the water recovery. The current model of the DOC system has exemplified consistency in its data and is prepared to undergo extensive testing at other NASA centers.

References

1. Flynn, M., Fusco, J., Kliss, M., Gormly, S., Richardson, TMJ., Hannon, A., Howard, K., Cath, T., Adams, VD., Childress, A., (2008) Advanced Development of the Direct Osmotic Concentration System, Proceedings of the 38th International Conference on Environmental Systems, San Francisco, CA
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3. Flynn, M., Gormly, S., Cath, T., Adams, VD., Childress, A., Howard, K., Hannon, A., Richardson, TMJ., Shaw., H., (2008) End of the Year Progress Report: Year 4 Advanced Development of the Direct Osmotic Concentration System, NRA #03-OBPR-01

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